Short Report

Morphology of the torn rotator cuff

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ABSTRACT

The morphological characteristics of shoulders with torn rotator cuffs were determined using 41 embalmed specimens. The following parameters were measured in the supraspinatus (SSP), infraspinatus (ISP) and subscapularis (SSC) muscles: the length, thickness and width of the extramuscular tendon; the length of the intramuscular tendon; the length and width of a tear, if present, muscle fibre length; and muscle volume. The cross-sectional area (CSA) of the tendon was measured on the photographic image of slices of the tendon using an image analysis system, and the CSA of the muscle was calculated by dividing the muscle volume by muscle fibre length. The rotator cuff was intact in 11 shoulders. A partial-thickness tear of the cuff was present in 12 shoulders, a full-thickness tear of the SSP in 11 shoulders, and a full-thickness tear of more than 2 tendons in 7. Overall incidence of full-thickness tears of the rotator cuff was 44%, and that of partial-thickness tears 29%. With increase of tear size, the functional tendon length (extramuscular tendon length plus tear length) increased by a statistically significant amount in the SSP, ISP and SSC, whereas muscle fibre length decreased in SSP and ISP. It is concluded that the increased functional tendon length and decreased muscle fibre length are the main morphological changes that make the rotator cuff a physiologically abnormal unit. Surgical repair of the torn cuff would be expected to improve these anatomical changes and restore the kinetics of the glenohumeral joint. Our data encourage early repair of rotator cuff tears at a stage when these anatomical changes are still reversible in patients, such as manual labourers and athletes, who need functional shoulders.

Key words: Shoulder; rotator cuff tears; tendon rupture.

INTRODUCTION

The rotator cuff tear is a common pathological condition at the shoulder. The incidence of full-thickness tears of the rotator cuff at autopsy or on anatomical dissection ranges from 7 to 26.5% (Smith, 1835; Keyes, 1933; Wilson & Duff, 1943; Yamanaka et al. 1983) and that of partial-thickness tears from 13 to 37% (DePalma et al. 1949; Yamanaka et al. 1983). Clinically, muscle weakness is a common finding in patients with rotator cuff tears. Pain can cause muscle weakness, but when pain is abolished by injecting local anaesthetics into the glenohumeral joint, muscle weakness still exists (Kirschenbaum et al. 1991; Zuckerman et al. 1991). Theoretically, if a tear is

confined to a single tendon and the continuation of the tendon fibres persists, the force produced by the muscle should be transmitted to the humerus through the remaining tendon. Therefore, muscle weakness should not be present in such cases if the muscle is capable of producing the same force as an intact muscle. The muscle atrophy commonly observed in patients with rotator cuff tears may of course explain the muscle weakness. However, morphological changes in musculotendinous structures may also cause the functional deficit. Wilson & Duff (1943) reported that tendon length increased when there was a tear of the cuff. They considered this phenomenon was due to the elongation of the tendon itself. On the other hand, Skinner (1937) and Petersson (1984)

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stated that the elongation of the torn cuff tendon was due to the retraction of the muscle, not to elongation of the tendon. We hypothesised that when there was a tear, the tendinous portion would become longer and the muscle belly would become shorter. This will eventually result in muscle weakness. The purpose of this study was to determine the effect of a rotator cuff tear on the morphology of the cuff and its associated structures and to consider the possible functional consequences.

MATERIALS AND METHODS

Specimen preparation

Forty-one embalmed cadaveric shoulders (average age 84 y, range 64–96 y) were studied. These specimens were obtained from bodies donated to the Mayo Foundation, with various causes of death. Shoulders where there had been previous surgery, fractures, or tumours were excluded. At the time of embalming, the upper limbs were at the side of the trunk and the elbows were either extended or slightly flexed and the shoulders slightly internally rotated. The skin, superficial fascia, acromion, coracoid process, and all muscles except the rotator cuff were removed. The superficial surfaces (bursal sides) of the supraspinatus (SSP), infraspinatus (ISP) and subscapularis (SSC) were carefully examined to detect any superficial tears. If there was a superficial tear, the size (maximal length and width) was measured using a digital caliper. The cuff muscles were then elevated from the scapula and the tendinous portions were carefully detached from the capsule. Attachment between the SSP and the superior capsule, and between the SSC and the anterior capsuloligamentous structures were so tight that sharp dissection was necessary. After elevating the cuff muscles to their insertions on the humerus, the deep surface (articular side) of these tendons was carefully examined and the size of any tear was recorded. If the tear was full thickness, its size was measured from both superficial and deep sides. After these measurements, the tendons were detached by a clean cut from the inside out at the point of insertion. Teres minor was separated from ISP. The interval between ISP and teres minor could easily be identified when these tendons were observed from the articular side.

Measurements

The length, thickness and width of the tendinous portion of the cuff muscles were measured using a
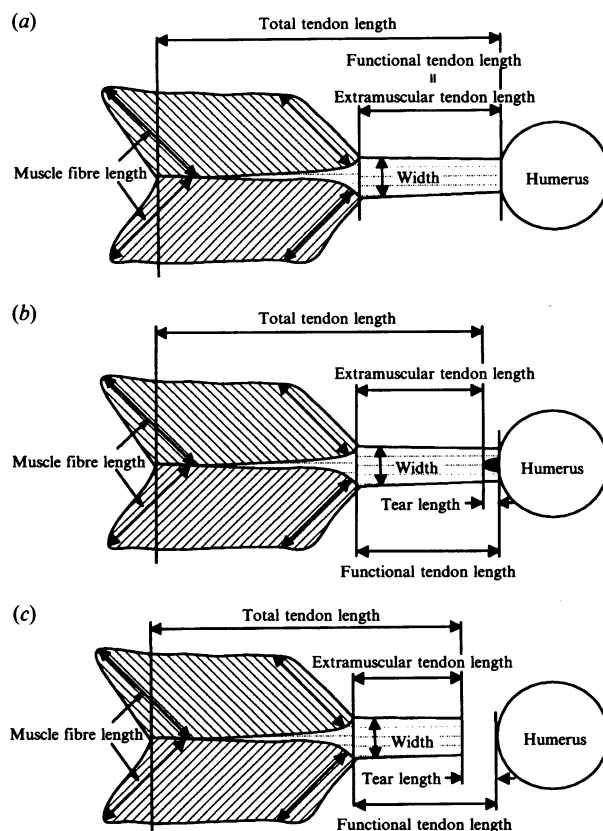

Fig. 1. Measurement parameters. Functional tendon length = extramuscular tendon length plus tear length. Total tendon length = extramuscular plus intramuscular tendon length. In intact SSP tendon (a), the extramuscular tendon length is equal to the functional tendon length. (a) Intact cuff; (b) small tear of the SSP tendon; (c) larger tear of the SSP tendon.

digital caliper (Fig. 1). The extramuscular tendon length was measured on the articular side of the tendon, from the distal end of the tendon to the musculotendinous junction at the midportion of the tendon of SSP and ISP. SSP is a circumpennate muscle with a single intramuscular tendon. ISP has a few intramuscular tendons which combine together to form a major intramuscular tendon. In ISP, therefore, we divided the muscle fibres along the major intramuscular tendon and measured the length of this tendon. In contrast, SSC is a multipennate muscle with 4 or 5 intramuscular tendons. It is known that the uppermost 2 or 3 intramuscular tendons are long and attach to the main tendon (Klapper et al. 1992). We chose to measure the length of the second-most superior intramuscular tendon. The distance from the distal end of the tendon to the most proximal end of the intramuscular tendon was defined as *total tendon length*. The sum of the extramuscular tendon length and the tear length was defined as *functional tendon length*. This was equal to the extramuscular tendon length if there was no tear. In some cases, there was no
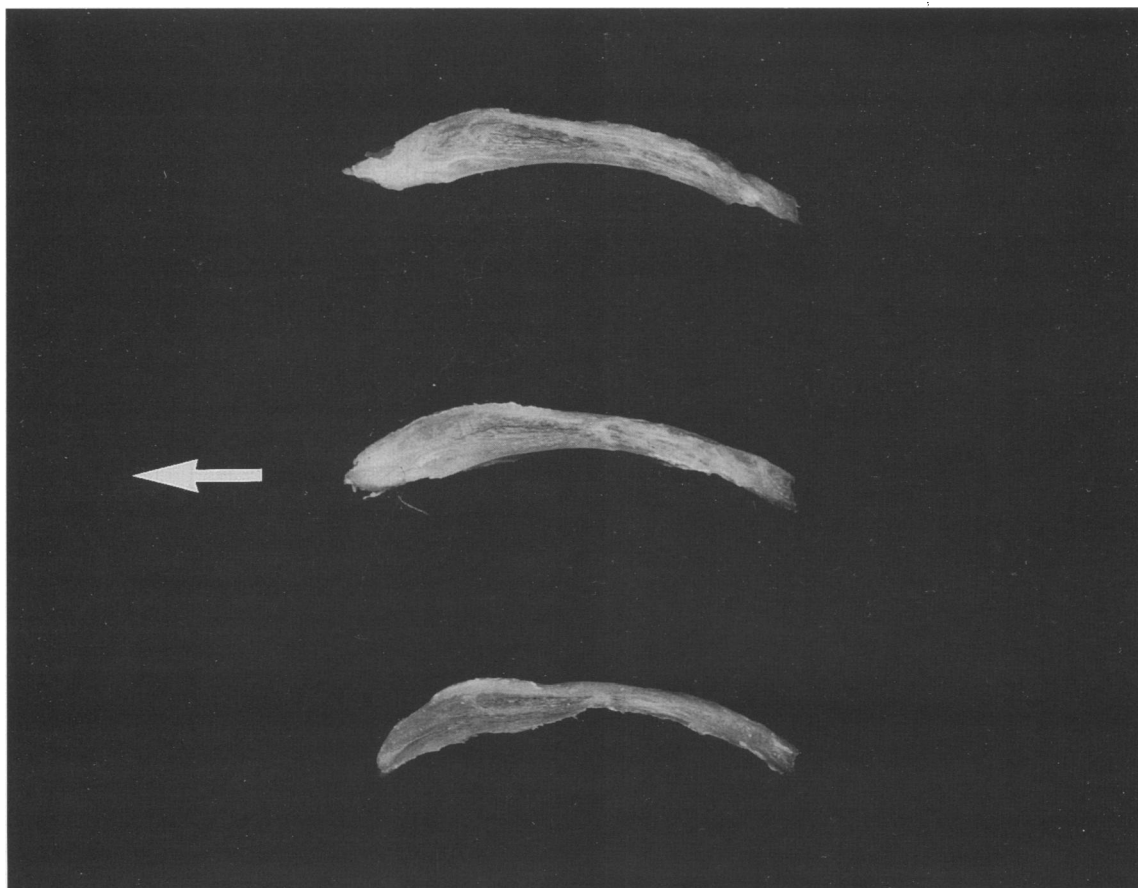
Fig. 2. Sections of the supraspinatus tendon at 3 levels from distal to proximal. The top slice is the distal portion and the bottom one is the proximal portion. The arrow indicates the anterior direction. The anterior part of the tendon is thicker than the posterior part.

continuity of the SSP tendon fibres with the humerus. However, the SSP still seemed able to function because the force produced by the SSP could be transmitted through the remaining cuff tendons along the edge of the tear. This was the reason why the term functional tendon length was used. Finally, muscle fibre length was measured as the most distal and proximal fibres of the two parallelograms, and the average length was determined as the muscle fibre length (Fig. 1). After these measurements, the extramuscular tendon was resected from the muscle and muscle volume was measured by water displacement.

The extramuscular tendon was sectioned into thin slices perpendicular to the tendon fibres while the tendon was placed on a tendon holder. It was not until this stage that an intratendinous tear, if present, could be observed and categorised as a partial-thickness tear. The distal, middle and proximal slices were photographed (Fig. 2). The cross-sectional area (CSA) of these tendon slices was measured on the photographs using an image analysis system (JAVA; Jandel video analysis system, Jandel Scientific, Corte Madera, CA). Also, the CSA of the muscle was calculated by dividing the muscle volume by muscle

fibre length. From these data, a ratio of tendon CSA to the muscle CSA was determined.

The tendon of the long head of biceps (LHB) was identified when the glenohumeral joint was disarticulated and the width of the tendon was measured at its widest intra-articular portion.

The length of the scapula from the superior angle to the inferior angle was measured. For the purpose of statistical analyses, one-dimensional measurements (length, width and thickness) were normalised by dividing the raw data by the scapular length and multiplying by 100.

Statistical analysis

The sample size was relatively small and as a normal distribution was not observed, nonparametric statistical analysis was employed. The effect of cuff tear on the tendon parameters (length, width, thickness and CSA) and on the muscle parameters (volume, fibre length and CSA) was analysed using the Kruskal–Wallis nonparametric test. An analysis of variance on the ranks of the variable of interest and the corresponding multiple comparison test (Duncan's

multiple range test) to assess the differences between the various tear groups were used.

RESULTS

Incidence of rotator cuff tear

Among 41 shoulders, intact rotator cuff tendons were observed in 11 shoulders (27%), a partial-thickness tear of SSP was observed in 12 shoulders (29%), full-thickness tear of the SSP was observed in 11 (27%), full-thickness tear of the SSP and ISP in 3 (7%), and a massive tear of SSP, ISP and SSC in 4 (10%). This totalled 18 out of 41 full-thickness tears (44%). We categorised the cuffs into 4 groups: (1) intact cuff; (2) partial tears comprising partial-thickness tears of the SSP; (3) small tears comprising full-thickness tears of the SSP; and (4) large tears with tears of more than 2 tendons.

Length, thickness and width

The normalised data for length, thickness and width are listed in Table 1. In SSP, the extramuscular tendon length showed the smallest values in the large tear

group, but the difference was not significant. The total tendon lengths were significantly shorter in the small and large tear groups than those of the intact and partial tear groups. Functional tendon length was significantly larger in the large tear group than in the partial and small tear groups, which in turn were significantly larger than that of the intact tendon group. There was no significant difference in thickness or width between groups. Fibre length showed the smallest value in the large tear group. In ISP, the large tear group showed a significantly longer functional tendon length. There was no significant difference in thickness or width. Muscle fibre length was shortest in the large tear group. The SSC showed a significant difference only in the functional tendon length; the large tear group showed the largest values. There was a significant effect of a tear on the LHB width; the LHB width was the narrowest in the intact cuff group.

Cross-sectional area and muscle volume

The muscle volumes and the CSAs of the tendon and muscle are shown in Table 2. The tendon CSA of ISP was significantly larger in the full-thickness tear

Table 1. *Normalised data**

	Intact cuff (n = 11)	Partial tear (n = 12)	Small tear (n = 11)	Large tear (n = 7)	*P* value
SSP					
Tendon length					
Extramuscular	18.2 ± 2.8	19.7 ± 4.5	15.8 ± 5.5	15.3 ± 3.8	ns
Total	40.8 ± 10.3^a	45.0 ± 9.0^a	35.1 ± 7.8^b	32.6 ± 10.7^b	0.0433
Functional	18.2 ± 2.8^a	24.6 ± 9.6^b	31.0 ± 8.8^b	41.8 ± 9.1^c	0.0001
Tendon width	15.3 ± 3.0	16.0 ± 3.8	15.8 ± 5.1	14.1 ± 2.4	ns
Tendon thickness	2.2 ± 0.4	2.4 ± 0.7	2.5 ± 0.7	2.6 ± 0.6	ns
Muscle fibre length	27.8 ± 5.0	31.0 ± 6.3	25.5 ± 6.0	23.5 ± 5.4	ns
ISP					
Tendon length					
Extramuscular	23.2 ± 4.3	23.3 ± 3.2	19.4 ± 4.2	26.6 ± 7.4	ns
Total	56.5 ± 13.7	58.9 ± 11.7	46.4 ± 9.0	52.8 ± 12.7	ns
Functional	23.2 ± 4.3^a	23.3 ± 3.2^a	19.4 ± 4.2^b	46.7 ± 18.4^c	0.0022
Tendon width	15.9 ± 2.9	17.5 ± 3.9	16.4 ± 4.4	17.0 ± 4.5	ns
Tendon thickness	2.3 ± 0.4	2.3 ± 0.6	2.6 ± 0.7	3.0 ± 1.1	ns
Muscle fibre length	35.9 ± 4.6	40.2 ± 7.2	29.8 ± 7.4	26.5 ± 8.8	ns
SSC					
Tendon length					
Extramuscular	19.3 ± 4.5	20.0 ± 5.0	19.6 ± 3.4	18.4 ± 6.0	ns
Total	45.1 ± 11.5	49.7 ± 11.3	43.1 ± 9.9	44.1 ± 11.2	ns
Functional	19.3 ± 4.5^a	20.0 ± 5.0^a	19.6 ± 3.4^a	37.3 ± 14.3^b	0.0399
Tendon width	19.2 ± 2.2	21.0 ± 4.6	19.9 ± 5.2	18.1 ± 4.1	ns
Tendon thickness	3.0 ± 0.4	2.8 ± 0.6	3.0 ± 0.9	3.2 ± 0.6	ns
Muscle fibre length	22.5 ± 5.8	27.8 ± 4.1	26.4 ± 5.5	29.9 ± 4.5	ns
LHB					
Tendon width	4.7 ± 1.0^a	6.5 ± 2.5^b	6.6 ± 2.2^b	7.1 ± 0.6^b	0.0075

* (Raw data/scapular length) × 100; values are means ± S.D. SSP, supraspinatus; ISP, infraspinatus; SSC, subscapularis; LHB, long head of biceps.
a, b, c In each row, those with the same letter are not significantly different.

Table 2. *Cross-sectional areas and volumes*

	Intact cuff (n = 11)	Partial tear (n = 12)	Small tear (n = 11)	Large tear (n = 7)	P value
SSP					
T-CSA, cm^2	0.7±0.2	0.7±0.2	0.8±0.2	0.9±0.3	ns
Muscle volume, cm^3	30.5±12.7	26.1±10.4	23.7±9.0	18.5±19.5	ns
M-CSA, cm^2	7.1±3.6	5.9±2.2	6.0±1.6	4.4±3.0	ns
T-CSA/M-CSA × 100	12.4±6.4	13.3±4.8	15.4±7.8	26.0±13.6	ns
ISP					
T-CSA, cm^2	0.8±0.2[a]	0.7±0.2[a]	0.9±0.1[b]	0.8±0.2[b]	0.0328
Muscle volume, cm^3	63.2±27.3	64.7±31.4	59.9±19.8	52.5±44.3	ns
M-CSA, cm^2	10.9±4.9	11.5±6.3	13.7±5.3	11.6±5.0	ns
T-CSA/M-CSA × 100	8.9±6.3	6.6±2.0	7.2±3.2	8.2±3.9	ns
SSC					
T-CSA, cm^2	1.5±0.4	1.4±0.4	1.6±0.3	1.3±0.4	ns
Muscle volume, cm^3	88.1±26.1	80.6±34.5	81.2±18.0	72.5±70.0	ns
M-CSA, cm^2	26.3±13.4	19.8±7.5	20.7±5.6	20.3±19.0	ns
T-CSA/M-CSA × 100	7.1±3.9	7.9±3.4	8.6±4.3	8.2±3.3	ns

Values are means±S.D.
T-CSA, tendon cross-sectional area; M-CSA, muscle cross-sectional area; SSP, supraspinatus; ISP, infraspinatus; SSC, subscapularis.
[a,b] In each row, those with the same letter are not statistically different.

groups than in the others, but this was not observed in SSP and SSC. Muscle volume, muscle CSA and the ratio of tendon CSA to muscle CSA did not show any significant differences between groups.

DISCUSSION

The most remarkable finding was that functional tendon length was significantly greater in the large tear group. The increased functional tendon length indicates that the musculotendinous junction shifted further from the greater tuberosity. The shortening of muscle fibre length in SSP and ISP is consistent with this conclusion. Both of these findings indicate that the torn musculotendinous unit is at a biomechanical disadvantage in exerting and transmitting force. These morphological findings may explain the muscle weakness observed in patients with rotator cuff tears.

It is known that the tendon of the long head of biceps becomes widened when there is a rotator cuff tear (Skinner, 1937; Burkhead, 1990; Matsen & Arntz, 1990). It was confirmed quantitatively in this study. The dynamic stabilising function of the long head of biceps has been clarified by recent biomechanical studies (Itoi et al. 1993, 1994). The widening of the biceps tendon is probably due to the functional compensation of biceps to the glenohumeral instability caused by rotator cuff tears.

The morphological changes of the torn cuff (elongated functional tendon length plus muscle atrophy) seem to explain the muscle weakness in patients with rotator cuff tears, which is commonly observed

clinically (Brems, 1987; Walker et al. 1987; Kirschenbaum et al. 1991). When the functional tendon length is increased, rehabilitation may not effectively increase the strength of the muscle. This is the limitation of conservative treatment (Itoi & Tabata, 1992). In contrast, one of the biggest advantages of surgical repair of the cuff is correction of this elongated functional tendon length which cannot be achieved otherwise. Thus surgical repair is desirable in patients such as labourers and athletes who need highly functional shoulders. However, if the correction is done at an advanced stage after the tear when the anatomical changes are established and irreversible, a good result cannot be expected. For this reason, if surgical treatment is to be performed, it should be done before the anatomical changes are too advanced. This has already been demonstrated in a clinical study (Bassett & Cofield, 1983). Our study supports this concept from a morphological standpoint.

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